The Maritime Timeline Analysis and Requirements Toolset (M-TART)

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Background

When the North American Aerospace Defense Command (NORAD) agreement was renewed in 2006, Maritime Warning (MW) was added to the mission set. Since then, there has been much debate as to what MW actually constitutes and where the Command and Control boundaries lie. This is further complicated for the United States, where the Commander of NORAD is also the Commander of United States Northern Command. The general consensus has been that NORAD MW brings together information and data provided by the activities of multiple agencies of both the United States and Canadian governments to provide a unique bi-national perspective and, if required, issue a warning to the governments of the United States and Canada.

Unlike the air domain, where the roles and relationships of the various agencies involved are well defined and understood, particularly since the events of September 11, 2001, the agencies involved in the maritime domain have far more complicated and varied relationships. A simple metaphor is to view the air domain relationships as a spider web of sorts, where the information, command and control pathways are many, but defined and traceable. The maritime domain can then be viewed as a pot of spaghetti noodles; very difficult to trace and constantly changing. This makes the decision space for MW complicated to comprehend and visualize. Out of this, several different questions are posed:

1. If you are going to produce a warning, when should you issue it?

2. Once you know when the warning needs to be issued, to whom should it be sent?

3. Lastly, do we have the systems and relationships in place to have enough information to be able to issue a warning to the correct people at the right time?

Approach

In 2008, the Defence Research and Development Centre for Operational Research and Analysis (DRDC CORA) team located at NORAD headquarters was approached to help quantify the time and space problem of maritime warning by NORAD J32 (Maritime Warning - Operations). Due to the team's previous
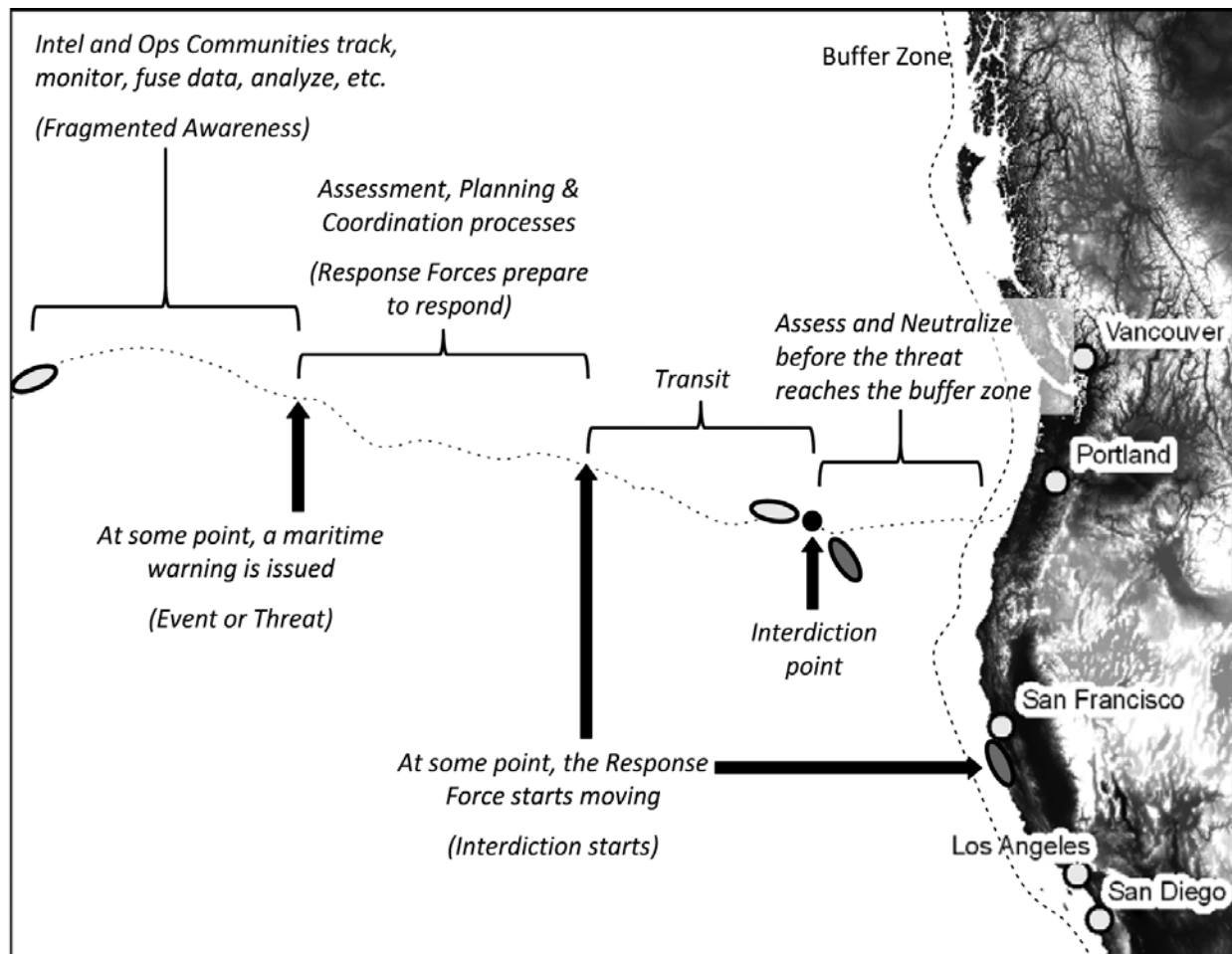
Figure 1. Graphical representation of the time and space problem of Maritime Warning.

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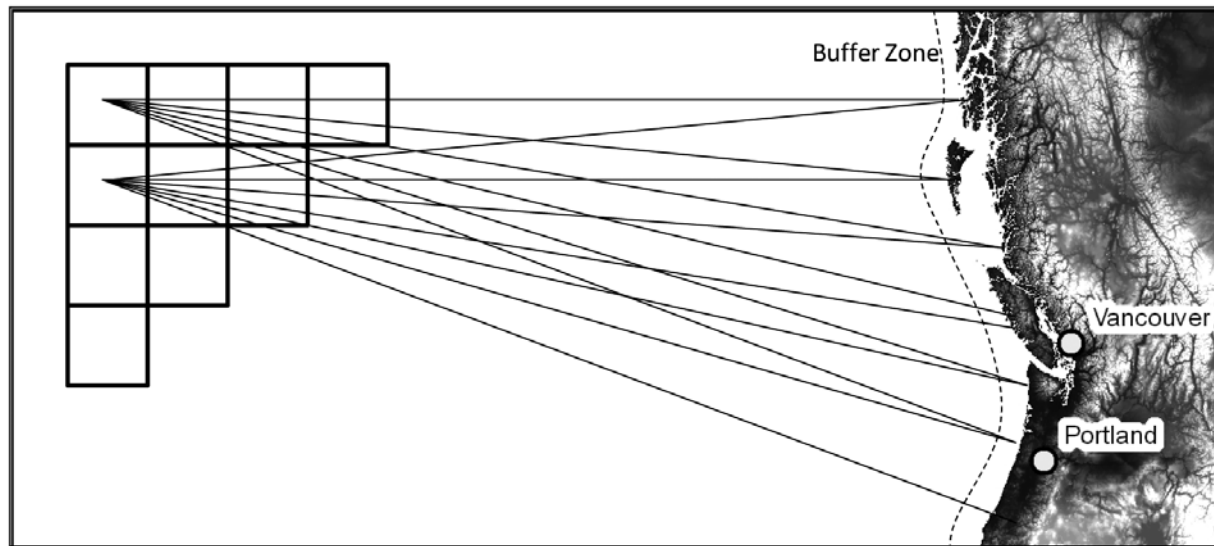Prescribed by ANSI Std Z39-18

Figure 2. Graphical representation of the threat model used in M-TART.

experience examining similar problems in the aerospace warning and control domain, they were well suited to take on this problem.

The team's approach was to develop a deterministic model to represent the maritime timeline from warning to completion of response, entitled the Maritime Timeline Analysis and Requirements Toolset (M-TART). Figure 1 illustrates the basic problem. The simplest way to view it is to consider a single ship track across the ocean, a single response force capability, and a buffer zone that must be enforced by the response force.

Before any warning occurs, government agencies develop specific awareness of maritime activities based on their individual mandates. From a whole of government approach, this can be viewed as fragmented awareness, as many of the departments only share information subject to both the limitations defined by law and a need-to-know culture. At some point in this process, information about a specific vessel may become significant enough to warrant either issuing a warning or sharing with other departments and agencies to determine whether or not a warning needs to be issued.

Once a warning has been issued, the clock is started. First, there are a series of events that need to occur. These include the planning, assessment, and coordination of response processes. Of these processes, the amount of time it takes for a response force to get underway can be the limiting factor, and this only starts once the decision is made to get the response force underway. Although Figure 1 shows a maritime response force capability, the response can be provided by either a maritime or airborne platform.

Once the response force has left its base, it takes a finite amount of time to reach the intercept point. The intercept point is calculated as the distance away from the buffer zone whereby the intercept force will be able to stop or alter the course of the threat vessel while still keeping it out of the buffer zone. Note that this assumes the destination of the threat vessel is known, so that the response force can position itself in the correct spot. Another way of viewing it, however, is that the response force will move in such a manner that they will always perform the intercept at the last minute, thus ensuring that they know where the threat vessel is. In either case, perfect or near-perfect surveillance and/or reconnaissance capabilities are implied.

If the threat can be intercepted at the appropriate distance away from the buffer zone, the mission is considered a success, i.e., the probability of success is 1 for that particular warning point and threat route. By calculating success at multiple points along the threat route, the minimum required warning distance can be determined for that particular threat / response force / buffer zone combination. This represents the tactical utility of the model, whereby a single individual scenario can be analyzed.

In order to look at the problem from a strategic perspective, one can abstract the previous tactical example into a bigger picture view. First, consider multiple possible warning points across the ocean. For each warning point, there are multiple possible threat routes to the coast. Drawn as Great Circle routes, this picture now defines the unknown threat (which could be identified at any of the warning points) and the unknown destination (as shown by the multiple Great Circle threat routes for each warning point). A generic example of this is shown in Figure 2.

Then, for each warning point, an average probability of success can be calculated from the probability of success for each of that warning point's threat routes. If the points are sufficiently close together, the area around each warning point can be assumed to have a similar probability of success, allowing us to construct probability of success density plots for the ocean as shown in Figure 3a (where the lighter colors indicate a higher probability of success) and the corresponding probability of success curve based on distance from the coast is shown in Figure 3b.

We now look at the effect of modeling threat behavior. By default, the model considers all of the threat routes from each warning point to be equiprobable. While this assumption seems valid for
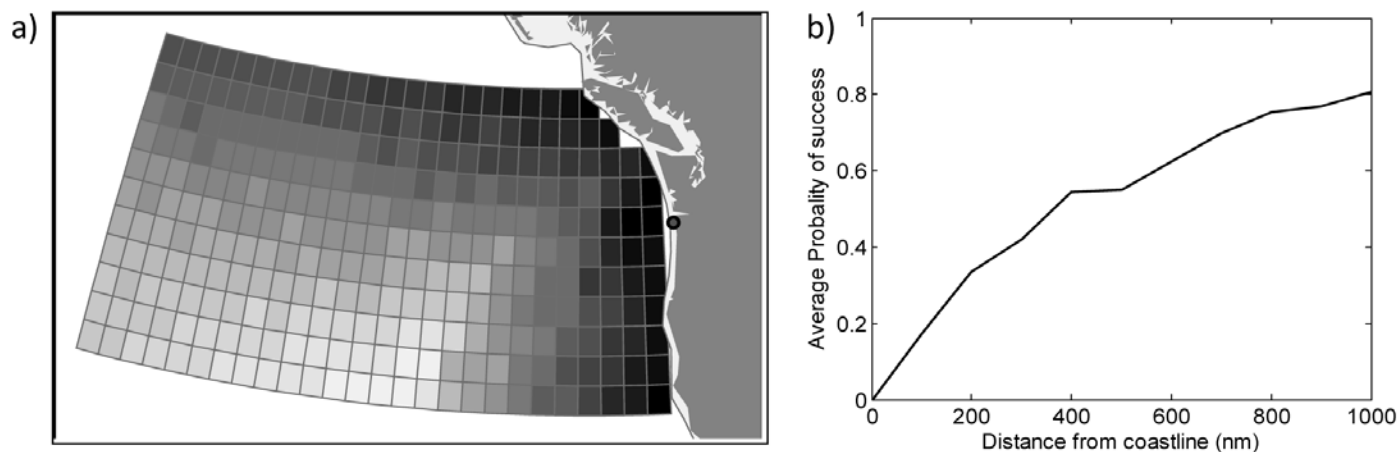
Figure 3. Example of a) probability of success density plot and b) corresponding probability of success curve.

warning points far from the coast, it also seems likely that as a threat approaches the coast, it will be more likely to head to the closest point on the coast (in the case of a threat simply trying to make it to the coast). This can be modeled by assigning each threat route a probability of occurrence, determined by its relative distance to the coast when compared to the other threat routes. By using the relative magnitudes of 1 over the distance to the coast, we are causing the threats with a shorter distance to the coast to be weighted higher. We can also apply a weighting exponent to the distances, thus making the shorter threat routes to be even more likely.

Since this weighting factor is used in the determination of the average probability of success, it only affects warning points where the probability of success is not 0 or 1, i.e. affecting the shape of the probability distribution curve between 0 and 1. The effect of the weighting factor is illustrated in Figure 4 which shows the average probability of success along set distances from the coast for weighting factors of 0, 1, and 2. The darker regions on the map indicate a lower probability of success, the lighter a higher probability of success. In each of the maps, the bottom left corner is 100% probability of success and remains unchanged. Similarly, the region directly in front of Cannon Beach (the square dot on the coast) is close to 0% probability of success and so also remains unchanged. As the weighting factor increases, we see the colors along

the coastline getting darker as the threat in the cells is more likely to head directly to the coast, thus lowering the average probability of success for that region. Determination of a value for the weighting factor can be determined by historical data if available or by subject matter expert opinion if not.

Up to this point, we have only considered one response force. Multiple response forces can also be modeled. In the simplest case, each response force location will only have a single capability. In this case each response force response capability is analyzed against each warning point threat route and if at least one can make it to the intercept point, then success is declared for that threat route. If multiple response forces can make the intercept, then a redundant success capability is recorded.

The above approach of using a single response force for each basing location is useful to develop a quick, generic understanding of high-level capabilities; however, it is likely that the response force capability at each basing location will vary with time. This occurs as response forces go in and out of maintenance cycles and alternate capabilities are substituted. If, from a strategic perspective, we are trying to understand capability over a longer period of time, over a year for example, then we need to capture this variability of availability.

Consider, again, our simple example in Figure 1 with one threat and one response force basing location. We now add multiple response force capabilities

at this basing location, each with a fixed probability of availability where the total of these probabilities does not exceed 1. This assumes that overlapping capabilities at the same location will not occur and is based on the assumption that the most capable response force would be used. For a given warning point along the threat route, we calculate the success or failure for each of the response forces at the single base, resulting in an average probability of success for that base over the considered time period.

From our definitions, the only way the probability of success for that point can equal 1 is if all response force capabilities being considered are successful and the sum of the response force capabilities equals 1. This concept is then extended to calculating the average probability of success for a warning point by repeating the above calculation for the multiple threat routes.

Our next consideration is multiple response force locations, each with time-varying capabilities. Unlike the temporal activities on a given base, which are assumed to be coordinated and therefore considered to be dependent, we have chosen to assume that the response force capability at any given time for a base is independent of the response force capabilities at that same moment in time at the other bases. This assumption of independence is useful in simplifying the average probability of success for a particular point on a given threat route, as it allows us to define the probability

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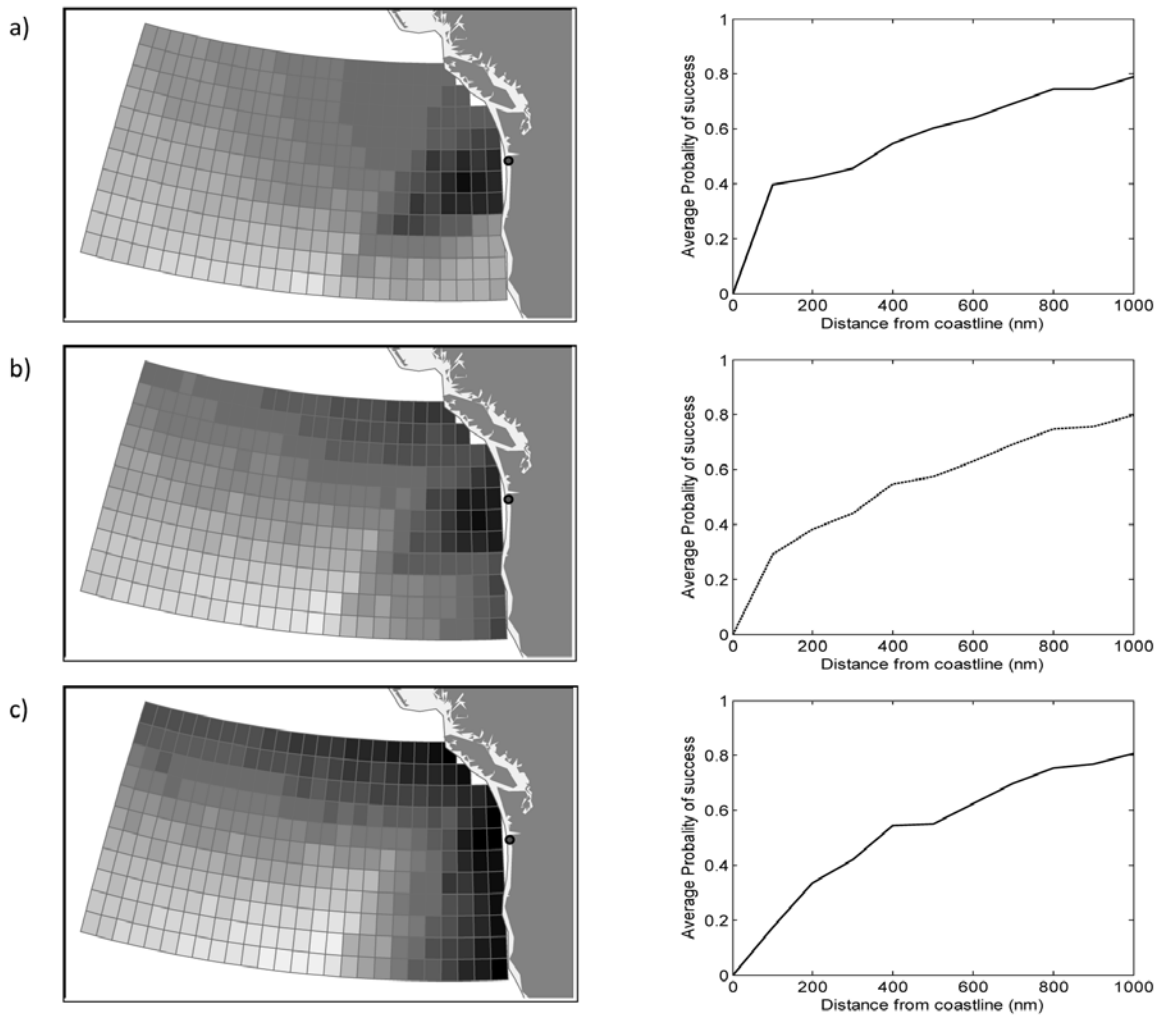
Figure 4. Effect of threat behavior factor m on average probability of success.
a) m=0, b) m=1, and c) m=2

of success against each threat route given multiple response force locations as 1 minus the probability of all the response force locations failing.

Thus far, this paper has shown the approach taken to determining probability of success based on warning locations, threat behavior, and response force posture. In describing the underlying mathematics in this paper, descriptions of some of the additional variables and algorithms used to make the model as accurate as possible have not been covered. What follows are some of the key features and parameters of the model that ensure realistic results are obtained.

To realistically model both threat and response force behavior, we have incorporated a custom-built land avoidance model that ensures sea surface vessels do not travel over land. In doing so, we have also accounted for the fact that different vessels will maintain different distances from land based on their characteristics. The model allows the user to specify different land proximity distances for the individual threats and the response forces. For airborne response forces, land avoidance can be disabled.

In addition to land avoidance parameters, each response force can be assigned individual capabilities. For example, transit speed and endurance will be unique to each type of response force. Similarly, the amount of time that is required to neutralize a threat is dependent on both the response force and the type of threat. Lastly, the basing location of the response force will often dictate both readiness time and how long before maximum transit speed can be reached, determined by base geography and activity levels.

Utility

The outputs of M-TART can be used in multiple ways, from tactical to strategic. From a tactical perspective, it serves to inform decision makers of the risk they

assume by delaying warning or response activities based on real-world threat locations and current response force postures. The model allows for very quick analysis of single threat events. Deployed forces can also be entered into the model, allowing for decision makers to understand the difference between planned risk and real-time tactical risk.

From an operational perspective, the tool allows planners to understand the decision space around a particular operation and even look at the effects of various response force options. As an operational decision aid, it can be used to understand the implications of how much is known about any given vessel for any given position in the ocean with respect to the defined protected area(s). As an example, during a special event occurring in a coastal location, operational planners can use M-TART to understand the best combination of response force locations and readiness times while operating under the command and control limitations. The output of M-TART defines a decision to warn line, whereby any location between that decision to warn line and the coast might result in a failure to stop a threat.

From a strategic perspective, the outputs of M-TART are particularly applicable. First, the tool has the ability to calculate and show a high level perspective for coastal defense capabilities. The model can be used to look at typical traffic patterns, which then gives an indication of risk, based on a complicit threat; e.g., the container ship with a dangerous cargo of which the captain and crew are not aware. It can also be used to look at the adversary that does not follow traditional routes or approaches. In this case, modeling the threat as described above will represent the worst case scenario, whereby the threat is weighted towards trying to reach the coast as quickly as possible. As the threat routes are simply an input into M-TART, almost any conceivable type of threat can be modeled.

Using the average probability distance calculations, the model can aid in the formulation of requirements for warning,

i.e., we want to have a defined probability of success against complicit targets and another against non-complicit targets, which translates to specific distances from the coast. We can also identify surveillance requirements for critical areas, as it is difficult to warn and respond against a target if its location is not known.

This last point segues nicely into the final use from a strategic perspective, that of defining information sharing requirements. The outputs of the M-TART define where information sharing has to occur, for seldom in the maritime world is all of the information required to issue a warning collected and processed by a single organization. The outputs articulate in time and space requirements for information sharing between agencies, departments, and governments if the desired warning requirements are to be met.

Finally, from a force posture perspective, the model captures the load requirements placed on the individual response force bases. This can also be viewed as the utility of a base or how critical it is or could be to a particular type of response or threat.

In all of the preceding utility cases, M-TART is fully scalable from the large vessel, blue ocean response to the small boat, littoral response.

Limitations

Although M-TART provides a comprehensive picture of maritime warning and response capabilities, there are some factors that have been identified to be incorporated into the next phase of development. Perhaps of most significance is modeling the effects of surveillance and reconnaissance activities. Currently, uncertainty in a threat's position can be accounted for by slowing down the speed of advance of the response force. Using this approach, we allow for the fact that the response force may move more quickly, but has to alter course more often and travel farther than the computed optimal course.

The desired approach is to incorporate surveillance coverage capabilities to determine in which regions we can identify

threats (and even assign a probability of detection, classification, and identification). We will then add reconnaissance capabilities to the model which will influence the response forces' capability to respond to the threat.

Another desired function in the model is the optimization of response force posture. A desired capability would be to be able to determine the most effective response force posture given some constraints such as basing locations and response force capabilities.

Conclusion

In this paper we have documented and demonstrated a tool that can serve to improve our understanding of requirements for maritime warning, response, and domain awareness (in particular information sharing.) The toolset is scalable both from the tactical to the strategic and from the small to the large vessel threat. It can incorporate multiple response force capabilities, both air and maritime. Coming back to the initial three questions posed at the beginning of this article, the model can answer when and to whom a warning should be issued. These answers can be used to determine whether the required capabilities exist. In addition to providing a means to visualize the time and space continuum of Maritime Warning, the M-TART is also intended to complement other tools used to look at how we see, use, and consider response force posturing in the maritime domain.